Natural Resources Institute

Global Climate Change Research

1991 Status Report

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U.S. Department of Agriculture
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Natural Resources Institute

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A COMPILATION OF GLOBAL CLIMATE CHANGE RESEARCH AT THE BELTSVILLE AGRICULTURAL RESEARCH CENTER CY 1991

Donald T. Krizek

INTRODUCTION

This report covers the activities of scientists at the Beltsville Agricultural Research Center (BARC) involved in research on global climate change research. The report covers work done primarily in four laboratories in the Natural Resources Institute in the areas of hydrology, remote sensing, systems research, and climate stress effects. Work conducted in the Plant Science Institute in the Molecular Biology Laboratory and Weed Science Laboratory is also included.

SECTION 1.

This section covers highlights of research conducted in CY 1991. A short description is given of the purpose, accomplishment, and significance of the research. For further information, the reader is referred to the Annual CRIS Reports.

SECTION 2.

This section contains a list of peer-reviewed papers published during 1989 to 1991.

SECTION 3.

This section contains a list of abstracts of papers published during 1989 to 1991.

SECTION 4.

This section contains a selected list of papers submitted for ARS approval between January 1990 and December 1991 followed by an interpretive summary and abstract of the manuscript. This section was obtained through the ARS TEXTRAN (Technology Transfer Automated Retrieval System) and is available upon request.

SUMMARY

BARC scientists are actively involved in research to help better understand possible physical and biological changes that might result from global climate change. Research is underway: 1) to develop improved data bases and models of plant growth; 2) to determine possible hydrologic changes; 3) to develop improved radiative transfer models; 4) to understand the biochemical and physiological mechanisms of adaptation to CO_2 enriched atmospheres, air pollutants, and increased UV-B radiation; and 5) to determine the interactive effects of CO_2 and other environmental factors including tropospheric ozone, UV-B radiation, and water stress.

DISCLAIMER

The author accepts full responsibility for any errors of omission or commission that have been made. Persons inadvertently omitted from inclusion from this compilation are encouraged to contact me by phone (301-504-5324) or by fax (301-504-7521). Technical questions concerning specific areas of research should be directed to the contact scientist listed.

SECTION 1

RESEARCH ACCOMPLISHMENTS

1991

1991 ANNUAL REPORT ON GLOBAL CLIMATE CHANGE RESEARCH AT BARC

A. HYDROLOGIC STUDIES

MONSOON '90 - AN INTERDISCIPLINARY FIELD EXPERIMENT FOR QUANTIFYING BASIN SCALE HYDROLOGIC FLUXES IN SEMIARID REGIONS

An interdisciplinary field experiment in evaluating the water and energy fluxes of a semi-arid watershed was conducted in Arizona over the summer of 1990. Ground truth and remote sensing measurements covered a wide range of spatial and temporal scales. This data is being utilized in energy and water balance models which employ remote sensing to improve our capabilities of integrating hydrologic fluxes to the basin scale. The findings can then be incorporated in large scale atmospheric models simulating the interaction of hydrologic processes with the atmosphere for semiarid climates. This will ultimately yield more reliable modeling of the impacts of climate change on the hydrologic cycle over different ecosystems.

CRIS 1270-13000-004-00D Dr. W. Kustas

SNOWMELT MODEL TESTED WORLDWIDE IN DIFFERENT CLIMATES

The Snowmelt-Runoff Model (SRM) has been tested around the world in different climates to establish baselines for use in comparisons of various climate change scenarios. SRM, a simple degree-day model with physically derived parameters, has been applied to over 50 basins in 15 different countries. SRM performance has been uniformly high for existing conditions (average $R^2 = 0.84$ and average volume difference = 3.8%) in all climate regions tested, and when consistent climate change scenarios are available in these regions, the model can be utilized to estimate a range of hydrologic responses that will allow formulation of possible management strategies.

CRIS 1270-13000-004-00D Dr. A. Rango

HYDROLOGIC RESPONSE TO POTENTIAL CLIMATE CHANGE IN WESTERN NORTH AMERICAN BASINS

Projected climate changes in mountain basins of western North America will significantly influence snow accumulation, snowmelt, and subsequent water yield. The Snowmelt-Runoff Model (SRM) has been used on the Rio Grande (Colorado), Kings River (California), and Illecillewaet River (British Columbia) with various climate change scenarios. Results indicate that in wet years floods will become more numerous and in dry years drought will be more frequent. A redistribution of flow will also take place so that there will most likely be a widening of the gap between water supply and water demand in most river basins.

CRIS 1270-13000-004-00D Dr. A. Rango

B. STUDIES ON REMOTE SENSING

REMOTE SENSING OF ABSORBED RADIATION AND PHYTOMASS PRODUCTION

Linear relations between phytomass production and absorbed photosynthetically active radiation (PAR) have been reported for a wide range of plant species. Other work has shown that absorbed PAR may be estimated from remotely sensed observations. The combination of these two concepts provides the basis of a physically-based agronomic monitoring system. For both corn and soybean, absorbed PAR was linearly related to remotely sensed reflectance measurements. The rate of accumulation of phytomass per unit absorbed PAR was greater for corn than for soybean. These results indicate that remotely sensed measurements contribute valuable information concerning energy and mass accumulations in plant canopies.

CRIS 1270-66000-010-00D — Dr. C. S. T. Daughtry

C. SYSTEMS RESEARCH

A TWO-DIMENSIONAL SIMULATOR OF PLANT GROWTH, AND WATER AND SOLUTE TRANSPORT

Crop simulation models often suffer in their predictive capabilities because they often have very simple representations of soil process. The Systems Research Laboratory scientists have coupled process-level crop simulation models with the two-dimensional, finite element model SOILSIM. This will greatly improve the modeling of plant growth and solute movement under a range of climatic conditions. The soybean model GLYCIM has been interfaced with SOILSIM and the Cotton Production Model (CPM) will incorporate SOILSIM.

CRIS 1270-66000-012-00D — Dr. D. Timlin

ESTIMATING EFFECTS OF CLIMATE CHANGE ON SOYBEAN PRODUCTION

In order for U.S. agriculture to adequately respond to global climate changes, a sound understanding of their effects on major agronomic crops is necessary. Effects of temperature and CO_2 elevation on soybeans are documented in the literature. However, the implications for regional production have not been investigated. The current work seeks to extend the use of simulation modelling of soybean growth to estimate the effects of global climate change on regional soybean yields. Using the simulation model GLYCIM in combination with the yield sampling methodology of the National Agricultural Statistics Service, USDA, yield estimates under future climatological conditions will be obtained. This research is vital to assess the effects of global climate change on this important crop so that adequate policy responses can be created and implemented.

CRIS 1270-61000-012-00D — Dr. J. Haskett

CARBON DIOXIDE AND TEMPERATURE EFFECTS ON COTTON

The effects of carbon dioxide concentration [CO_2], temperature, and their interactions were evaluated on cotton physiological processes such as growth, development, root growth, photosynthesis, and respiration. The study was conducted using controlled environmental cabinets with five temperature treatments of 15/7°C, 20/12°C, 25/17°C, 30/22°C, and 35/27°C (day/night) and CO_2 treatments of 350 and 700 μmol mol^{-1} at each temperature. Plant height and the rate of stem elongation increased with increases in temperature and CO_2 concentration. The number of main stem nodes and the node addition rate are temperature dependent. In addition, CO_2 has no effect on these processes. The developmental processes such as squaring, flowering, and boll opening were driven by temperature. Photosynthesis increased linearly with increases in CO_2 concentration. This database is critical for the development of process-level crop simulation models which can be used for predicting the effects of future climate change on agriculture.

CRIS 1270-6100-012-00D Dr. V. R. Reddy

D. BIOCHEMICAL AND PHYSIOLOGICAL EFFECTS

IMPACT OF DROUGHT STRESS ON COTTON SEED AND FIBER PROPERTIES

Global change may result in shifting patterns of seasonal temperature and rainfall. The effect of severe drought (water withholding) on developing seeds in bolls of mature cotton plants grown under greenhouse conditions was investigated, using two cultivars of Gossypium hirsutum - Deltapine M-8 and DPL 51. Analyses of fiber and seed properties were made on mature seed from bolls on upper and lower branches of plants receiving 10 to 30 days drought stress. Data for fiber properties of seed (M-8) from bolls receiving 25 to 30 days drought stress provided evidence that these fibers were immature and took up little stain following a standard dye test. Radiolabeling studies with DPL 51 for incorporation into protein revealed a stage specific sensitivity to drought for continued incorporation into storage proteins. These findings will be used for development of a module for predicting changes in seed and fiber quality due to drought stress for field-grown cotton.

CRIS 1270-11210-004-00D Dr. E. L. Vigil

ELEVATED CARBON DIOXIDE CONCENTRATION REDUCES RESPIRATION

Elevated atmospheric carbon dioxide concentrations increase photosynthesis, and it was thought they would also increase respiration. However, when respiration rates were examined in ten species grown at twice the current atmospheric carbon dioxide concentration, it was found that respiration rates were reduced at elevated carbon dioxide in nine of the species. Interactions between carbon dioxide concentration and temperature were examined in alfalfa and orchard grass leaves. Results indicate that the sensitivity of respiration to temperature declined with time in leaves grown at elevated carbon dioxide. This resulted in a larger effect of carbon dioxide on respiration as temperature increased. Inhibition of respiration by elevated carbon dioxide has potentially important consequences to crop carbon balance and to the future trend of atmospheric carbon dioxide concentrations.

CRIS 1270-21000-011-00D Drs. J. A. Bunce and L. H. Ziska

RAPID PHOTOSYNTHETIC ADJUSTMENT TO ELEVATED CARBON DIOXIDE

Elevated atmospheric carbon dioxide usually stimulates photosynthesis initially, but often physiological adjustments occur which decrease or eliminate the stimulation. Experiments with soybeans and sugarbeets used variation in light, temperature and nutrients to test the hypotheses that photosynthetic adjustment to elevated carbon dioxide resulted from feedback inhibition or nutrient deficiency. The patterns of response were not consistent with either hypothesis. In soybeans, a single dark period at 700 ppm carbon dioxide decreased photosynthetic rates the next day compared to control leaves kept at 350 ppm. This suggests a regulatory response, rather than a change in leaf composition was involved. In experiments with orchard grass and alfalfa, it was found that photosynthetic adjustment to elevated carbon dioxide increased with increased growth temperature in alfalfa, but decreased in orchard grass. The patterns of photosynthetic acclimation were consistent with a smaller effect of elevated carbon dioxide on growth rate at warmer temperatures in alfalfa, but a larger growth stimulation at warmer temperatures in orchard grass. A better understanding of these responses will be necessary in order to predict crop growth at elevated atmospheric carbon dioxide concentrations.

CRIS 1270-21000-011-00D Drs. J. A. Bunce and L. H. Ziska

ANTICIPATED INCREASES IN TEMPERATURE AND CO_2 MAY AFFECT SEED GERMINATION

We examined the influence of 35 and 70 Pa carbon dioxide pressure on germination in pea, corn, sunflower, soybean, amaranth, lambsquarters and alfalfa grown in controlled environment chambers at 20 and 30°C. Earlier seed germination (24-48 h) was noted at 70 Pa CO_2 for pea, corn, lambsquarters, and alfalfa. A significant increase in the total number of seeds germinated was also observed in lambsquarters and alfalfa with elevated CO_2. With the exception of amaranth, a 10°C rise in temperature did not influence the germination response to CO_2, although seeds overall germinated faster at the higher temperature. For amaranth, no significant germination was observed at 20°C, but earlier germination and a greater total germination percentage was noted at 30°C and high CO_2. Diurnal studies of seed imbibition showed a greater rate of water uptake for those seeds which responded to elevated CO_2. Results from this study suggest that changes in seed germination with anticipated increases in CO_2 and temperature may potentially alter stand establishment, crop cover and weed-crop interactions.

CRIS 1270-21000-011-00D Dr. L.H. Ziska

STARCH SYNTHESIS IN THE LEAVES OF CO_2 ENRICHED SOYBEAN PLANTS

An examination of the response of soybean leaf starch synthesis to increases in atmospheric CO_2 concentration was undertaken. Glycine max [L.] Merr. cv Amsoy plants were propagated in growth chambers maintained with 650 μmol m^{-2} s^{-1} white light, 14 h light-10 h dark cycle, 27°C continuous, and 65% RH, for 20 days post-emergence (PE) in an ambient atmosphere containing 330 μmol mol^{-1} CO_2 air (normal CO_2 plants). At 20 days PE, one-half of the plants were transferred to a growth chamber with identical conditions except that the atmosphere in the chamber contained CO_2 at 1000 μmol mol^{-1} air for 7 additional days (high CO_2 plants). After 7 days of high or normal CO_2 exposure, rates of foliar net photosynthesis (APS) were measured. Plant organs were sampled into liquid N_2, lyophyllized, extracted, and quantitated for starch, sucrose, and phosphorylated metabolites. APS rates for source leaves of high CO_2 plants (measured in 1000 μmol mol^{-1} CO_2 air) compared with those of normal CO_2 plants (in 330 μmol mol^{-1} CO_2 air) were respectively, 1136 and 683 μmol CO_2 fixed dm^{-2} h^{-1}. During illumination, high compared with normal CO_2 plants exhibited 2-7 times higher starch levels in all organs including leaves, stems, and roots. Leaves from high compared with normal CO_2 plants possessed, respectively, ≈50% and ≈7% of their dry weight as starch. In contrast, relative to normal CO_2 plants, foliar sucrose levels in high CO_2 plants only were 1.3 to 1.6 times higher in the leaves and only slightly higher or not different in the stems and roots. The foliar concentrations of photosynthetic intermediates, e.g. glycerate-3-P (PGA), fructose-6-P (F6P) glucose-6-P (G6P), and glucose-1-P (G1P), were, in the high CO_2 plants, approximately twice those in CO_2 normal plants. Thus higher foliar levels of PGA, F6P, G6P and G1P in the high CO_2 plants suggested that a causal factor of elevated starch accumulation was higher activity of one or more rate limiting enzymes in the starch synthesis pathway; e.g. PGA is a positive effector and G1P is a substrate for ADP Glucose pyrophosphorylase, a very rate limiting enzyme in the starch synthesis pathway. The results and interpretations of this study contribute to a continuing effort to understand the physiological responses of soybean plants as they grow in a global atmosphere where the concentration of CO_2 is increasing.

CRIS 1270-21000-014-00D

Dr. J. Michael Robinson

INTERACTIONS BETWEEN AIR POLLUTANTS AND ATMOSPHERIC CO_2

Open-top field chambers and remote sensing techniques were used to investigate the leaf spectral response of winter wheat, corn, and soybean grown under enriched CO_2 concentrations and O_3 or CO_2 x SO_2 stress conditions. Photosynthesis and canopy leaf area index reflectance measurements were taken to evaluate the potential of remote sensing data to estimate losses in crop productivity due to air pollution. Laboratory studies have also been conducted on snapbean and soybean in environmentally controlled fumigation chambers. Determination of polyamine levels and PS II chlorophyll fluorescence of leaf tissues in response to antioxidant treatments and O_3 stress were also conducted. Effects of CO_2 and O_3 individually were consistent with those reported previously. The CO_2 and O_3 interactions observed were generally consistent with a reduction of O_3 injury by increased CO_2. The significance of these studies was to incorporate remote sensing technology to detect and assess the impact of atmospheric gases as it related to global climate changes. We would expect the research to be utilized not only in the scientific community and government but to agricultural chemical companies as well.

CRIS 1270-21000-008-00D Dr. E. H. Lee

TEMPERATURE CROSS PROTECTION AGAINST SO_2 INJURY

The effects of temperature cross protection were investigated in two cultivars of coleus, differing in SO_2 sensitivity. Measurements were made of membrane lipid composition after 5 days of temperature pretreatment at 13 or 20C. Lipid composition at 20C revealed inherent differences between SO_2 sensitive 'Buckley Supreme' and SO_2 insensitive 'Marty'. Temperature hardening at 13C, which increased SO_2 tolerance, caused specific changes in membrane lipids. Determination of leaf free fatty acid pools and measurements of lipid peroxidation products further indicated a difference in metabolism between the two cultivars. These findings may help to elucidate the biochemical basis for SO_2 tolerance in plants.

CRIS 1275-24000-078-00D Dr. H. A. Norman

CANOPY ARCHITECTURE, CO_2 AND SPECTRAL QUALITY

Elevated atmospheric CO_2 may stimulate vegetative growth, altering mutual shading of adjacent plants in densely planted monocultures. Canopy shade reduces both photosynthetically active radiation and the ratio of red:far-red radiation, affecting the photochromic pigment phytochrome. Many types of controlled environment lighting provide little far-red radiation, thus circumventing normal changes in spectral quality and altering phytochrome photostationary state. Soybean dry matter accumulation was less inhibited by high density planting when daylight red:far-red ratios were simulated in growth chambers. Improved growth was associated with reduced axillary development and increased stem and petiole extension. As a result, light penetration into the canopy improved and canopy photosynthesis increased. Morphological changes probably resulted from changes in the photostationary state of phytochrome. The influence of elevated CO_2 will be investigated. These results should be of interest to physiologists conducting experiments with elevated CO_2 in controlled environments and to breeders searching for strategies to improve growth and yield in response to rising CO_2.

CRIS 1270-11210-002-00D Dr. S. J. Britz

ADVERSE EFFECTS OF AMBIENT UV-B RADIATION LEVELS ON CROP GROWTH

UV-B radiation exclusion studies were conducted under field conditions in New Delhi, India during July, 1990, using a polyester filter placed horizontally over the plot to exclude the direct component of solar UV-B radiation. This filter excluded most of the direct UV radiation in the 280-320 nm region and transmitted only 23 percent of the UV radiation at 320 nm. The visible radiation at ground level was about 86% of the unfiltered radiation. In general, mungbean plants grown under the UV-B filter grew faster, had longer internodes, and greater leaf size than those exposed to full sunlight. There was a significant increase in pod and seed number, and dry weight of pods and seed when the direct component of UV-B radiation was excluded. These preliminary findings suggest that plants under natural atmospheric conditions in New Delhi are already growing under above optimal conditions of UV-B radiation. These findings should be of interest to researchers and policy makers involved in global climate change assessments.

CRIS 8001-11210-758-00P Drs. Y.P. Abrol, A.Sharma,& U.K.Sengupta; Dr. D. T. Krizek, Cooperating Scientist

PHOTOPROTECTION MECHANISMS AGAINST DAMAGE FROM UV-B RADIATION

Sensitivity to ultraviolet-B radiation (UV-B, 280-315 nm) is generally reduced when background photosynthetically-active radiation (PAR) is high. The involvement of photosynthesis in the amelioration of UV-B damage was tested during short-term treatments at high PAR with high levels of supplemental UV-B and either "low" (450 vpm) or "high" (750 vpm) atmospheric CO_2. UV-B had little effect on cucumber leaf photosynthesis at low CO_2 but it inhibited leaf area expansion and plant growth. High CO_2 counteracted the effect of UV-B. In contrast, the accumulation of UV-absorbing flavonoid compounds was stimulated by UV-B exposure but was not affected by CO_2 enrichment. This result is consistent with the involvement of non- photosynthetic photoreceptors in the regulation of response to UV-B and should be of interest to physiologists seeking to assess the influence of elevated UV-B and breeders looking for traits that confer resistance to UV-B.
CRIS 1270-11210-002-01T Dr. S. J. Britz

INFLUENCE OF UV-B RADIATION ON POLYAMINES, LIPID PEROXIDATION & MEMBRANE LIPIDS

Cultivar differences in UV-B sensitivity in cucumber were first demonstrated at Beltsville in the mid-1970's. Current effort is being focused on establishing the biochemical basis for these genotype differences. UV-B sensitive (Poinsett) and UV-B insensitive (Ashley) cucumber were grown in the greenhouse for four weeks under 0 0r 12.2 kJ m^{-2} d^{-1} of biologically effective UV-B radiation to determine effects of increased UV-B level corresponding to approximately a 20% depletion in stratospheric ozone level at Beltsville on June 21. Elevated UV-B radiation caused an increase in concentration of the diamine putrescine and the polyamine spermidine in cotyledon and leaf tissues in response in both cultivars, but levels were not correlated with UB-B sensitivity. Lipid peroxidation, as quantified by measurement of malondialdehyde (MDA) was increased by UV-B exposure. Significant cultivar differences were observed, with increases in lipid peroxidation in both cotyledons and leaves being correlated with UV-B sensitivity. Determination of membrane lipid composition indicated slight decreases in the unsaturated/saturated fatty acid ratios as a result of UV-B exposure. In general, Poinsett had a lower unsaturated/saturated ratio of fatty acids than did Ashley. These results indicate that membrane lipids may be a target of UV-B damage and that differences in UV-B susceptibility of these two cultivars may involve differences in lipid metabolism.
1270-11210-003-00D Drs. G. F. Kramer, H. A. Norman & D. T. Krizek

UV-B RADIATION MODIFIES PLANT RESPONSE TO ELEVATED TEMPERATURES

The effect of ultraviolet-B (UV-B, 280-315 nm) radiation on the thermal sensitivity of cucumber was examined to assess the potential agronomic consequence of combined stratospheric ozone depletion and global warming. Using an enzymatic assay (involving triphenyl tetrazolium chloride) to assess tissue viability after temperature (50C) treatment, it was apparent that growth of cucumber under enhanced UV-B radiation levels increased their ability to withstand elevated temperatures. The results suggest that both enhanced UV-B radiation and elevated temperatures may result in similar cellular lesions. Therefore, plant adaptation to elevated UV-B radiation results in protection against high temperatures.

CRIS 1270-21000-001-00T Drs. C. R. Caldwell and A. Upadhyaha

ENHANCED TURNOVER OF THE D1 AND D2 PHOTOSYSTEM II REACTION CENTER PROTEINS UNDER UV-B IRRADIATION

The D1 and D2 heterodimer comprises the nucleus of the photosystem II (PSII) reaction center. D1 undergoes rapid degradation at low intensities of both visible and UV radiation, turning over at rates far exceeding those for other PSII proteins. The D2 protein degrades relatively slowly in visible light but in the UV its degradation rate increases considerably, approaching that of the D1 protein. Other PSII proteins are not as markedly affected. When a small amount of UV irradiation is added to saturating amounts of the visible light (as in sunlight) a synergistic stimulation of D1 degradation occurs, but even stronger stimulation of the D2 protein degradation is seen. Thus, a specific stimulation of the D2 protein degradation occurs in UV radiation, resulting in the D1-D2 heterodimer being the target of this damaging irradiation.

CRIS: 1275-21000-060-00D Dr. A. K. Mattoo

METABOLIC CHANGES IN BEAN PLANTS UNDER UV- AND BLUE-DEFICIENT ENVIRONMENTS

'Bush Blue Lake' snapbean plants, known to be sensitive to ozone pollution and other oxidant stresses were grown for 4 weeks in growth chambers in the presence or absence of UV and blue radiation to investigate the biochemical basis for bleaching observed previously under UV and blue-deficient low pressure sodium (LPS) lamps. Plants were grown at 300 μmol m^{-2} s^{-1} of photosynthetically active radiation (PAR) under: a) LPS lamps, b) a combination of LPS and supplemental blue (B) fluorescent lamps; or c) under cool white fluorescent (CWF) lamps. By 20 days under LPS lamps, the compound leaves and leaves of the lateral shoots had developed extensive chlorosis, crinkling of the leaf margins, and severe interveinal necrosis. Exposure of plants to LPS + B lamps greatly ameliorated these symptoms, while plants grown under CWF lamps were free of injury. Electrophoretic separation of leaf proteins from these plants revealed significant differences in protein profiles under the three radiation sources. These findings provide further biochemical evidence for the essentiality of blue/UV radiation in normal chloroplast development.

CRIS 1270-11210-003-00D

A. L. Fleming

SECTION 2

PEER-REVIEWED PUBLICATIONS

1989 - 1991

1991 ANNUAL REPORT ON GLOBAL CLIMATE CHANGE RESEARCH AT BARC

A. HYDROLOGIC STUDIES

Engman, E. T., G. Angus, and W. P. Kustas. 1989. Relationships between the hydrologic balance of a small watershed and remotely-sensed soil moisture. IAHS-AISH, Pub. No. 186, pp. 75-84.

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Rango, A. 1991. Worldwide testing of the Snowmelt Runoff Model with applications for predicting the effects of climate change, Nordic Hydrology 22:10. (Abstract)

Rango, A. and V. van Katwijk. 1990. Climate change effects on the snowmelt hydrology of western North American mountain basins, IEEE Transactions on Geoscience and Remote Sensing, GE-28(5), pp. 970-974.

Rango, A. and V. van Katwijk. 1990. Water supply implications of climate change in western North American basins. Proceedings of the Symposium on International & Transboundary Water Resources Issues, American Water Resources Association, Toronto, Ontario, pp. 577-586.

Rango, A., J. Thurman, W. Blackburn, F. Schiebe, and D. Woolhiser. 1991. Compilation and availability of Agricultural Research Service hydrological data for use in climate change studies. Proceedings of the NATO Workshop on Opportunities for Hydrological Data in Support of Climate Change Studies, Lahnstein, Germany, NATO Publications Series.

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Acock, B. 1990. Effects of carbon dioxide on photosynthesis, plant growth, and other processes. In ASA Special Publication No. 53, Impact of Carbon Dioxide, Trace Gases, and Climate Change on Global Agriculture. pp 455-60.

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SECTION 3

PUBLISHED ABSTRACTS

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